

NASA's New Radio Wave Propagation Experiment

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Abstract - Since the early years of satellite telecommunications, the evolution of systems has led to a strong increase in satellite capacity, a decrease of boarded equipment size and a significant cost reduction. From the technical point of view, the congestion of primary allocated frequency bands resulted in the use of higher and higher bands from L, S or C bands to X and Ku bands, and in the near future up to Ka, V and EHF bands. One of the main concerns with these higher frequency bands is the influence of the atmosphere on radio wave propagation. Until now, some studies have shown that the feasibility of such links seems to be guaranteed, especially in the Ka-band. Several propagation experiments have been conducted, mainly in mid-latitude climates, with the OLYMPUS, ITALSAT, and ACTS satellites. However, it is still necessary to determine what service availability will be supplied to the user, and to predict the behavior of these systems when affected by high fading conditions. In particular, the knowledge of propagation issues in wet climates has to be improved.

Satellite telecommunication links in the EHF band are disturbed by troposphere phenomena, which can severely degrade service quality. First, attenuation is caused by atmospheric gases (mainly oxygen and water vapor), by clouds (liquid water and ice particles) and by precipitation (hail, snow and particularly rain). Scintillation appears as rapid fluctuations of signal amplitude or phase caused by tropospheric turbulence in clear sky conditions or by precipitation. Depolarization is due to non-symmetrical particles such as raindrops, snowflakes, and especially ice particles.

To achieve prediction of such impairments, two kinds of models are available: statistical and deterministic. Statistical models, like ITU/R recommendations, use a semi-empirical approach and are quite well-suited for systems studies. Deterministic models are based on a physical description of phenomena, and therefore allow a better understanding of propagation effects. Input parameters are not always available for these models, so they are more adapted to in-depth case studies.

Until now, these statistical models have been validated up to Ka band (20/30 GHz) in temperate areas, in particular with the OPEX (OLYMPUS Propagation Experiment) campaign. Currently, the ITALSAT propagation experiment studies the validity of these models in the EHF band (40/50 GHz) in European countries. The ACTS campaign was concerned with the Ka-band (20/29 GHz) in the U.S.A.

The Ka- and V- band propagation experiment in the tropics will utilize either the EHF propagation payload on the French STENTOR satellite or the United States' GBS satellite. Both of these satellites contain a Ka-band beacon and STENTOR also contains a V-band

beacon. The propagation data will be collected by locating a ground terminal in Puerto Rico, which is located in a tropical rain region. The results from this experiment will be used to improve the statistical models in these higher frequency bands in wet climates.

New knowledge statement: High frequency propagation model validation will be enabled by the measured data collected in this experiment in tropical rain zones. Previous work, such as the ACTS Propagation Campaign, only contains data taken in dry to semi-tropical rain zones.

1.0 Introduction

There are strong indications that Ka-band frequencies will soon be fully exploited for Earth/space applications. Interest in the commercial sector is rapidly rising. Two types of systems are being considered by NASA: a geostationary earth orbit (GEO) and low earth orbit (LEO). The next generation of tracking and data relay satellites (TDRS) will use this band on an experimental basis. NASA is strongly considering the use of frequencies slightly above 30GHz for its deep space missions, and the U.S. military is already using 20 and 40 GHz links in its Milstar system.

The 20/30 GHz radio-frequency region offers three advantages for satellite communications over the lower frequencies of C and Ku bands. These benefits can be summarized as spectrum availability, reduced interference potential, and reduced equipment size. However, these benefits of the Ka band are not without a cost. The 20/30 GHz band is more susceptible to tropospheric impairment than the lower frequencies. Mitigating these tropospheric-induced losses, which can be accomplished at lower frequencies by providing a modest link margin, requires a more elaborate approach at the Ka-band.

To mitigate the effect of the Earth's atmosphere on 20/30 GHz frequencies a good understanding of the phenomenon is required. It is important that the propagation limitations of this band are recognized and that they are accounted for in system planning and design. To increase our understanding of Ka-band propagation effects, two propagation campaigns were implemented during the last decades. The first of these efforts was the Olympus propagation experiment that took place mainly in Europe from 1988-1992. This experiment used the Ku and Ka-band signals of the Olympus spacecraft for field measurements [1]. The second effort was the Advanced Communication Technology Satellite (ACTS) propagation campaign that took place mainly in the US and Canada from 1991-1996 [2]. Because the ACTS and Olympus campaigns lack understanding of propagation issues in the tropics (worse case), a new NASA propagation experiment is currently underway in conjunction with the French STENTOR mission. This paper will discuss the new NASA propagation campaign using the French satellite STENTOR.

2.0 Objective of NASA/STENTOR Propagation Campaign

The objectives of this campaign are stated as follows:

- 1- To provide a good understanding of Ka-band propagation issues in the tropical rain zone
- 2- To develop models for the prediction of the propagation-related anomalies
- 3- To develop tools for the mitigation of these anomalies

Making long-term measurements at multiple sites in a tropical rain zone and analyzing the collected data will achieve these objectives. Clearly, a timely and full dissemination of the

results to users of propagation data, i.e. the satellite communications community, is a prerequisite for a successful accomplishment of the above objectives.

3.0 Ka-Band Propagation Issues

For the sake of completeness, the primary Ka-band propagation effects are listed below:

Rain attenuation. Signal attenuation due to rain is the most severe propagation effect at Ka-band. This kind of loss can exceed 20 dB for small percentages of time.

Gaseous absorption. A loss close to 1 dB can be associated with oxygen and water vapor absorption.

Cloud attenuation. Clouds along the propagation path can attenuate Ka-band frequencies. Typical values are in the order of 1 dB or more.

Scintillation. This term refers to rapid fluctuations of signal amplitude. It is caused by time varying changes in the refractive index of the atmosphere. It can also be caused by rainstorms.

Depolarization. A transfer of energy from one polarization state into its orthogonal state can be caused by the atmosphere, mainly clouds and rain.

Atmospheric noise. The atmosphere has an equivalent black body temperature. At Ka-band frequencies, this temperature varies from about 10K to close to ambient temperature.

Wet antenna and snow on the antenna. Condensation and snow on the antenna causes additional signal losses. These losses can be as large as a few dB.

Reliable statistics are needed to predict the above effects for slant-path applications. Note that each effect is not only a function of frequency, but also of location, path elevation angle, and season (time). Since it is not possible to make observations at every location, the region of interest can be divided into several rain or atmospheric climatic zones. A climate zone is an area on the ground that has certain statistical attributes. For example, the characteristic that rain rates exceeding a given threshold occur at a certain probability would constitute a rain climate zone.

4.0 Propagation Terminal Description

The design of the terminal is based on dual circular polarization reception using digital signal-processing technology and using a single frequency radiometer for the determination of the absolute atmospheric-induced signal loss value.

The terminal uses a small antenna and a front end shared by the beacon and the total-power radiometer receiver. The radio frequency (RF) front-end enclosure is carefully temperature controlled to ensure radiometer stability. A simplified block diagram of the terminal is shown in *Figure 1*.

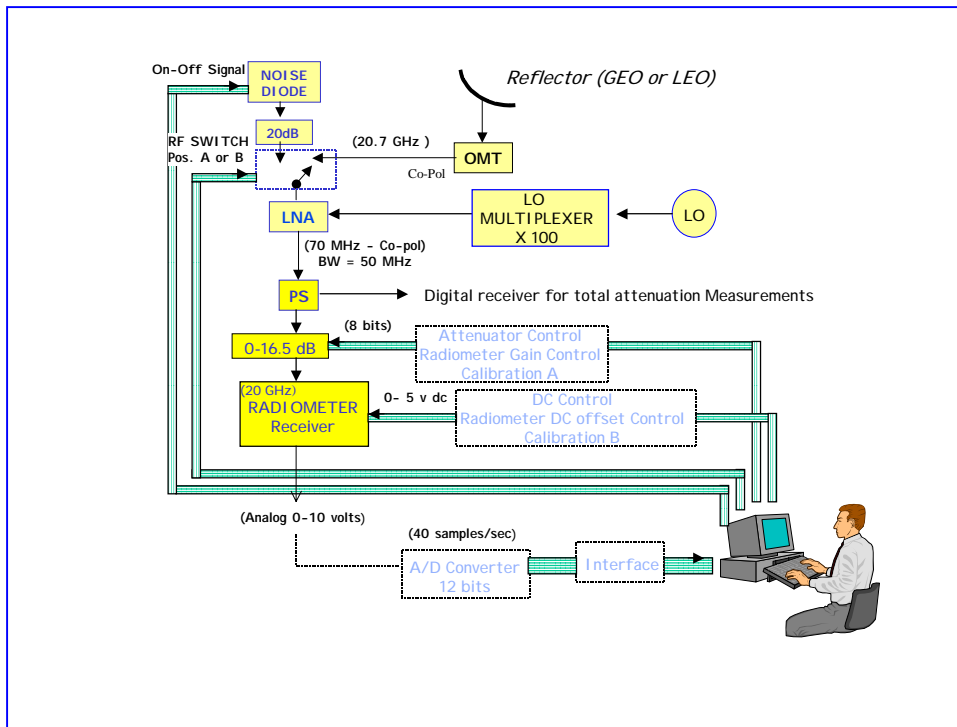


Figure 1 – System block diagram of the co-polarization and radiometer channel

The output of the 70 MHz IF signal is split into two paths. In one path, the signal is further downconverted to 455 KHz. The 455 KHz signal drives the digital receiver. The digital receiver performs a fast fourier transform (FFT) of the signal over a 200 KHz bandwidth during acquisition to locate the beacon signal. In the operational (tracking) mode, a narrow band FFT is used to drive a frequency-tracking loop. A major advantage of the digital receiver is that it acquires the signal in fewer than 3 seconds from any point within the 200 KHz bandwidth and reliably locks to the carrier beacon signal. If the signal is lost in a deep fade, it will be acquired as soon as the attenuation is less than about 25dB. The overall accuracy of the receiver is estimated to be better than 0.5 dB.

The second path of the 70 MHz IF output signal feeds the radiometer. The radiometer measures the noise power over a 50 MHz bandwidth. Calibration is performed automatically at frequent intervals by switching a low-loss coaxial switch ahead of the mixer to RF noise diode in series with an attenuator.

The PC-based data acquisition and control system (DACS) consists of three major components: data acquisition and control hardware, a personal computer, and software programs for data collection. Hardware is located in the IF chassis and collects data from beacon receivers, radiometers, environmental instruments, and system temperature sensors. This subsystem also controls the calibration of the radiometer channel.

The PC hardware receives all data transmitted from DACS, logs the data to disk, and displays the collected data for user viewing. The PC is placed indoors, while the rest of the DACS is located outdoors in the IF chassis. **Figure 2** shows the propagation terminal at the site in Humacao, Puerto Rico.



Figure 2 – Propagation Terminal at the University of Puerto Rico, Humacao

5.0 Calibrations and Preprocessing

The propagation terminal generates daily output files containing one second averages of the beacon receiver power levels, radiometer voltages and one minute averages of surface meteorological observations collected by the environmental sensors. A preprocessing programs converts the recorded radiometer data into one second average attenuation estimates, combines theses estimates with the beacon power level measurements to provide estimates of the unattenuated satellite beacon power levels radiated toward the propagation terminal, predicts the unattenuated beacon reference power levels for attenuation determination, and outputs both the radiometer and beacon attenuation estimates for further processing.

The preprocessing program also performs the periodic radiometer channel calibrations to maintain precise radiometer power level estimates based on the radiometer voltage measurements. The program also uses the surface meteorological observations to generate medium temperature estimates for the conversion of radiometer power measurement estimates into attenuation estimates and to generate sky brightness temperature estimates for the calibration of the radiometer channels during the periods with neither rain nor clouds.

The radiometer system is calibrated by adjusting the effective antenna efficiency values, to make the changes in estimated attenuation from the radiometer match the observed changes in beacon attenuation. This adjustments are valid for beacon attenuation values between 3 to 6dB. In addition adjustments of the side lobe contributions to the radiometer power measurements are required, to make the radiometer estimates of brightness temperature match the expected values calculated for periods with neither rain nor clouds.

The beacon attenuation estimates depend upon adequate estimates of the beacon reference power level that adjusts for the diurnal and shorter term variations of power radiated by the satellite. The reference level estimates are based on a fourth order harmonic curve fit to the reference level for the prior day with a one hour ahead prediction of the differences between the smoothed curve fit and weighted observations from a four hour period prior to making the predictions. The prediction of a least squares correction for differences between the smoothed estimate of the diurnal variation and the observed reference level is required to provide an adequate estimate of the reference level during periods with severe attenuation. Observations using the prediction and correction scheme show worst-case attenuation estimation errors of less than 0.5 dB during periods of rapid change when the earth eclipses the sun at the satellite.

Statistically, for a month of observations, the differences between that radiometer attenuation distribution estimates and the beacon attenuation distribution estimates are less than 0.1 dB for attenuation levels less than 5dB. This calibration scheme amounts to a least-squares fitting of the beacon attenuation estimates to radiometer attenuation estimates over a sliding interval of about four hours. The result is an estimate of the total attenuation due to all causes: rain, clouds, scintillation, wet antenna, or wet snow on the antenna.

6.0 Experiment Site

The experiment terminal is located in the University of Puerto Rico, Humacao campus. *Table 1* describes the site characteristics. Every month the raw data collected are sent to the Glenn Research Center for calibration and analysis. All anomalies or terminal downtimes are handled by students at the University.

Table 1 – Site Characteristics

Location	Latitude Deg.	Longitude Deg.	Azimuth Deg.	Elevation Deg.	Site Altitude
Humacao Puerto Rico	18.1487	-65.8385	108	37	70 m

7.0 Results Site Rain Statistics – 11 month

The terminal weather station has been taking rain/weather statistics (e.g., outside temperature, barometric pressure, relative humidity, tipping bucket data) since May of 2001. *Figure 3a and 3b* show the cumulative density distribution results. Notice that similar behavior of rain fall distributions has been observed in the two years of data collection. *Figure 3b* shows a comparison between the rain rate statistics collected at the ACTS locations and the new location in Humacao. Notice also the large deviation from the other sites. This clearly indicates that the rain rates in this location are very large in comparison with the other sites that were studied during the ACTS campaign.

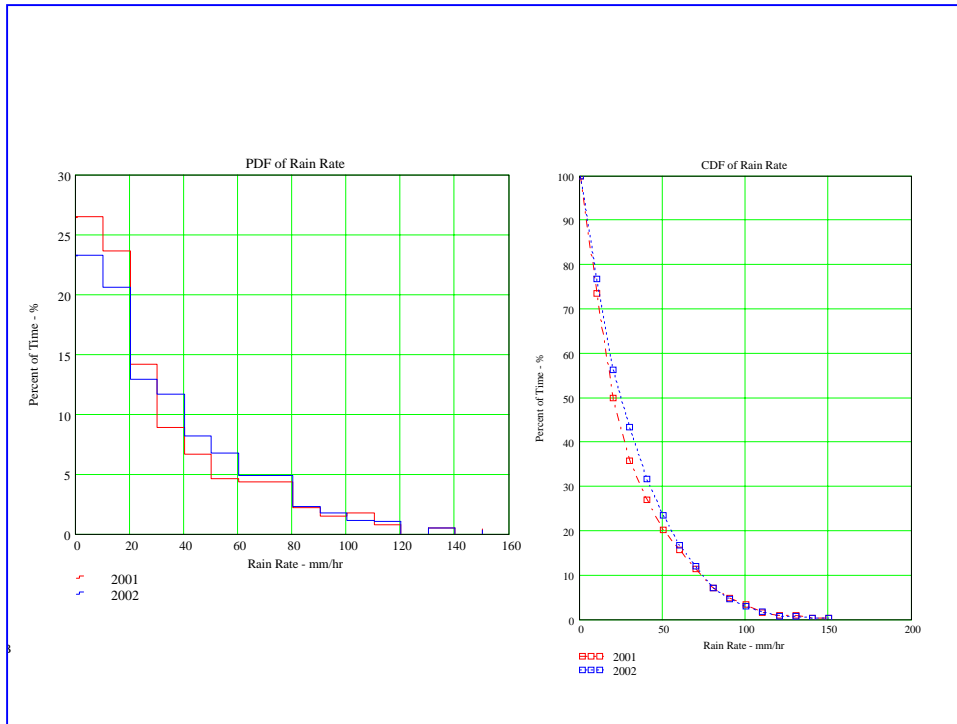


Figure 3a – Rainfall and rain rate statistics

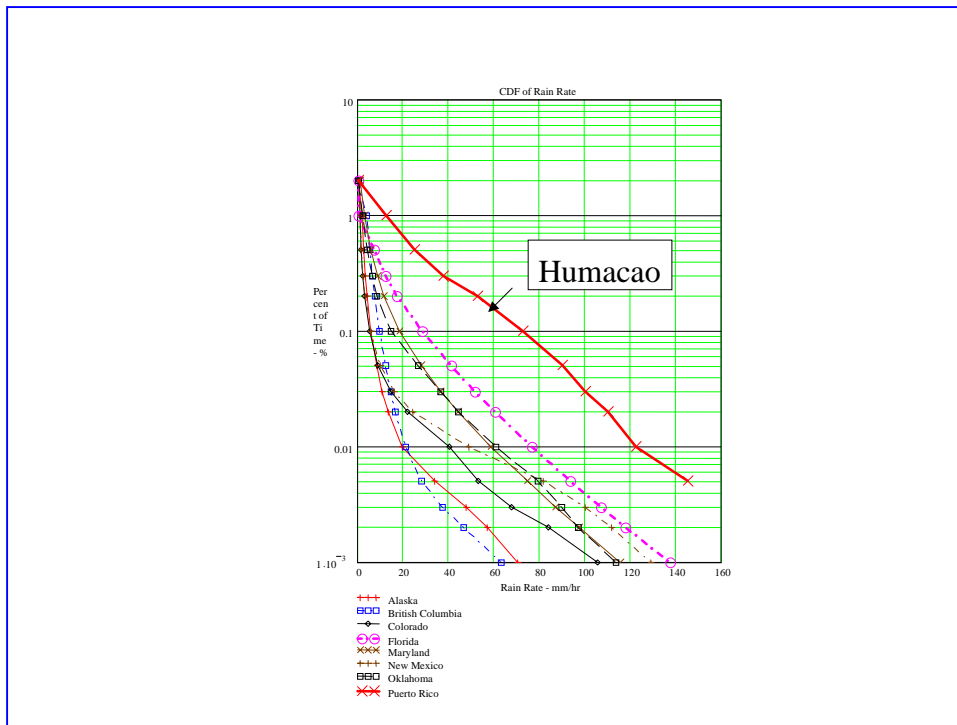


Figure 3b – Rain rate comparison with ACTS data collection and rain rate statistics

8.0 Results Beacon Statistics – 2 Month

The RF data collection began on April 2002. Statistics of the RF/beacon data with only two months of data shows no particular behavior pattern and no conclusion can be drawn based on the limited data collected. **Figure 4** shows a typical time series view of the collected data.

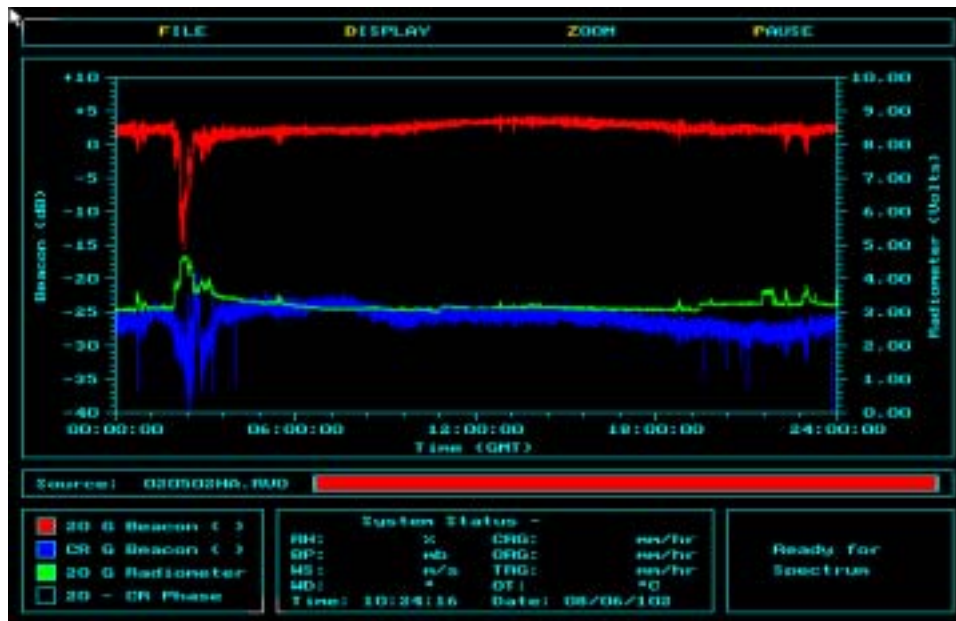


Figure 4 – Time series Co-polarization (red) and cross polarization (blue) and the radiometer output voltage (green).

9.0 Summary

This summary describes the new NASA experimental campaign for collecting Ka-band propagation data in the tropics. The objective of the experiment is to characterize satellite communication channels in the tropics of at least two fixed site terminals.

The terminals are identical and share the same software for data preprocessing. The data collected by these sites are archived at the Glenn Research Center for distribution to the user community. The first site began data collection on May 2002, and data analysis began in August 2002. The second terminal will be deploy and operational by October 2002.

References

- [1] OPEX Reference Book, Volume 1-5, ESA WPP-082, November 1994..
- [2] F. Davarian, D. Rogers and R. Crane “Special Issue on: Ka-Band Propagation Effects on Earth-Satellite Links,” *Proceeding of the IEEE*, vol. 85, no. 6, pp. 805-1024, June. 1997.